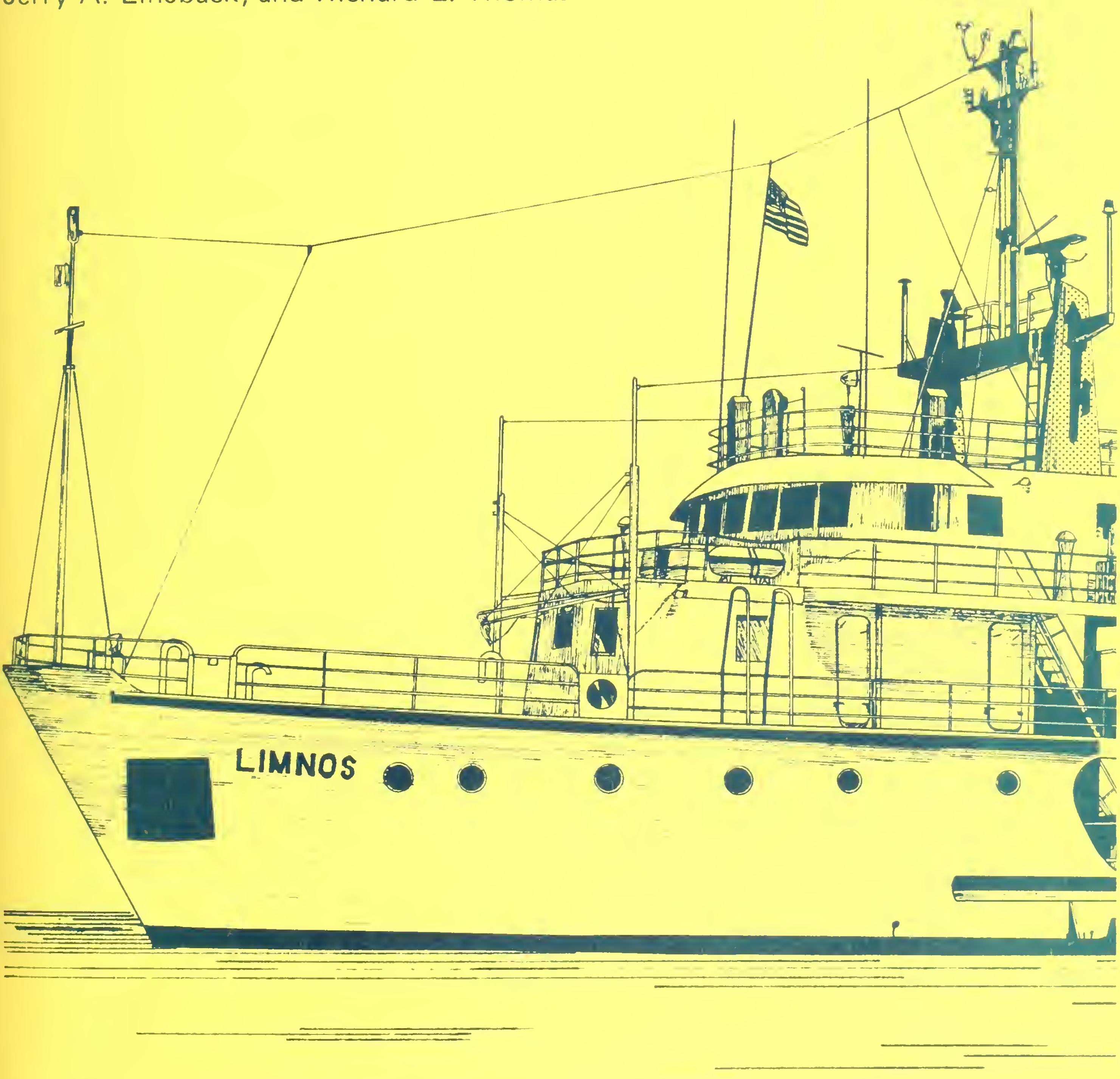
Geol Survey

LATE QUATERNARY SEDIMENTS OF LAKE MICHIGAN

STUDIES OF LAKE MICHIGAN BOTTOM SEDIMENTS
Number 13

Jerry T. Wickham, David L. Gross,
Jerry A. Lineback, and Richard L. Thomas



ILLINOIS STATE GEOLOGICAL SURVEY
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ENVIRONMENTAL GEOLOGY NOTES
Number 84
January 1978

Illinois–Geological Survey
Environmental Geology Notes . . .
EGN 84: Late Quaternary sediments of Lake Michigan. Jerry T. Wickham and others. January 1978.

26 p., illus., figs., tables. 28 cm.
(Its Studies of Lake Michigan bottom sediments, no. 13)

1. Sediments–Lake Michigan. 2. Geology, Stratigraphic–Quaternary.
I. Wickham, Jerry T. (Series)

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Abstract

A series of piston cores, gravity cores, and 5140 kilometers of subbottom echograms was obtained from Lake Michigan during a cruise aboard the C.S.S. *Limnos* in August 1975. After the echograms were correlated with the core descriptions, maps showing the thicknesses of several glaciolacustrine and lacustrine stratigraphic units were constructed. Isopach maps prepared from the echograms, which show the distribution of lacustrine deposits in Lake Michigan, were used to help identify the sediment sources of the units.

The maps revealed that the glaciolacustrine Equality Formation is discontinuous in Lake Michigan; however, in an area southwest of Grand Haven, Michigan, it displays a thickening that probably represents an offshore extension of the Allendale Delta of the glacial Grand River. The two lower members of the overlying Lake Michigan Formation are thickest in the deepwater basins of Lake Michigan. These lower members are composed of an extremely fine-grained red glaciolacustrine clay deposited from suspension. In contrast, the upper three units of the Lake Michigan Formation are thickest in a belt along the eastern side of the lake and consist of gray clay resulting from erosion within the Lake Michigan drainage basin by waves and streams. A large influx of sediments from streams in western Michigan and possible redistribution of shoreline erosion debris by lake currents causes the accumulation of gray clay to be greatest on the eastern side of the lake.

Acknowledgments

The August 1975 cruise of the C.S.S. *Limnos* in Lake Michigan was a joint effort. Support by the Canada Centre for Inland Waters included the ship, most of the shipboard personnel, and the geological laboratory work and interpretive work necessary to characterize the surficial sediment in the lake. The Illinois State Geological Survey provided shipboard personnel and geological interpretations of echograms. R. L. Thomas and D. L. Gross were chief scientists for the first 24 days of the cruise, and J. A. Lineback served as chief scientist for the last three days. All are indebted to Captain N. L. Keeping and his crew for excellence in all aspects of the cruise.

• R. L. Thomas is director of the Great Lakes Biolimnology Laboratory, Canada Centre for Inland Waters, Burlington, Ontario.

introduction

Lake Michigan, which covers parts of Wisconsin, Michigan, Indiana, and Illinois, ranks third in area of the Laurentian Great Lakes and is the only Great Lake entirely within the United States. A complex sequence of glacial till and glaciolacustrine and lacustrine sediments lie in a basin carved into Paleozoic bedrock beneath the lake. The distribution of Lake Michigan sediments is the result of events that took place during the waning stages of the last major continental glaciation (Wisconsinan) and during postglacial time (Holocene) (fig. 1).

Purpose

Stratigraphic, seismic, and sedimentological studies of the southern part of Lake Michigan have been published (Gross et al., 1970; Lineback, Ayer, and Gross, 1970; Lineback et al., 1971; Lineback and Gross, 1972; Gross et al., 1972; and Lineback, Gross, and Meyer, 1972 and 1974). Seismic profiling efforts and detailed programs for sampling lake sediments similar to the project reported here have been completed in the other Great Lakes by Thomas, Kemp, and Lewis (1972 and 1973) and Thomas et al. (1976). The results of this project are based on data obtained during an extensive research cruise by the Canadian Survey Ship *Limnos* during August 1975. Unlike earlier geological investigations of Lake Michigan, this cruise consisted of a systematic traverse over the entire lake basin, including Green Bay (fig. 2). The Pleistocene stratigraphic units previously recognized in the southern part of the lake (Lineback, Gross, and Meyer, 1972 and 1974) were mapped over the lake's entire extent. The stratigraphic framework described here complements detailed mapping and descriptions of surficial sediments based on the same cruise (R. L. Thomas and others, in preparation). Analyses of the chemical compositions of the sediments are underway at the Illinois State Geological Survey.

Methods

During August 1975, grab samples were collected at the intersections of a 14-by-14-kilometer Universal Transverse Mercator (UTM) grid over most of the lake bottom; a more detailed 7-by-7-kilometer UTM grid was used in Green Bay and in the northeastern corner of the lake (fig. 2). Grab samples were obtained from 280 of the 296 sampling stations in the grid network. At the remaining 16 stations, coarse lag gravels or bedrock hindered or completely prevented recovery of samples. Descriptions of all the samples are in preparation by Thomas. Thirteen cores up to 1 meter long

Series	Stage	Substage	Formation	Member
PLEISTOCENE	Holocene		Lake Michigan	Ravinia Sand
				Waukegan
				Lake Forest
				Winnetka
	Wisconsinan	Valderan		Sheboygan Wilmette Bed
				South Haven
			Equality	Carmi
			unnamed	Two Rivers Till
		Twocreekan		No deposits found
		Woodfordian	Wedron	Manitowoc Till
				Shorewood Till
				Wadsworth Till

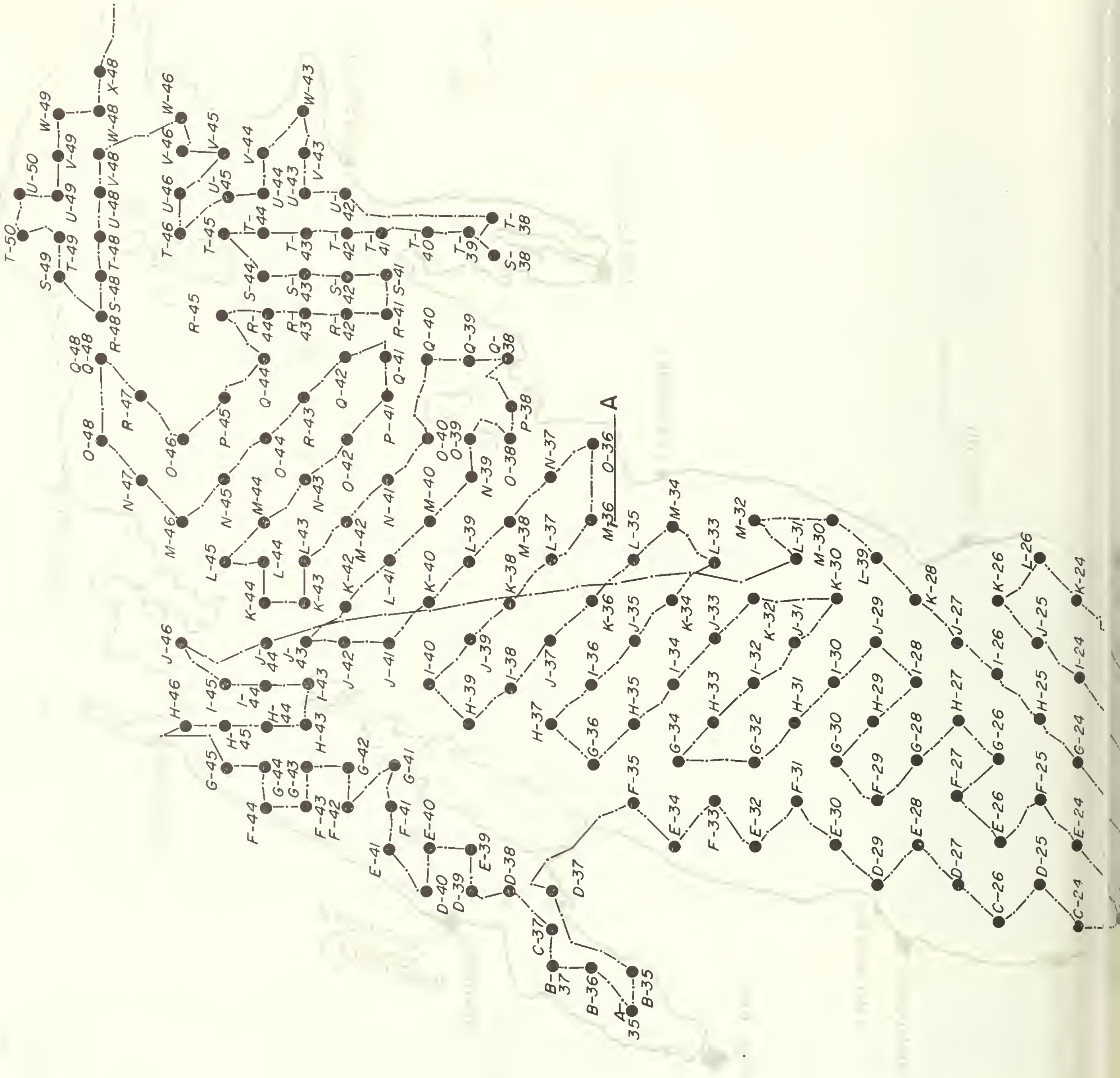
Figure 1. Late Pleistocene sediments underlying Lake Michigan

were collected by using a Benthos coring device. Five other cores up to 18 meters long were collected with a 550-kilogram Alpine piston-coring device.

The ship was navigated by means of a Decca 416 radar unit with a variable range marker. Fixes were determined upon arrival and departure at each sampling station and at 15-minute intervals between stations (fig. 2). The distances between the ship and two or more identifiable shorelines, docks, or major inland landmarks were determined by using the variable range marker. Locations were plotted on the navigation chart and recorded as longitude and latitude. The precision of the recorded positions is estimated to be within 500 meters in the center of the lake and somewhat more precise in nearshore areas.

Continuous profiles were made by a Kelvin Hughes MS26B echosounder operating at 14.25 kHz. The echosounder provided accurate records in areas underlain by lacustrine sediment and allowed little or no acoustical penetration in areas underlain by coarse gravel, till, or bedrock. Because Silver and Lineback (1972) determined the velocity of sound in lacustrine sediments cored from southern Lake Michigan to be within 10 percent of the velocity of sound in water, we used a uniform vertical scale in interpreting the profiles. Maximum acoustical penetration of the lake bottom was 35 meters.

Records from the 14.25-kHz profiling provide neither the sharpness of detail nor the depth of sediment penetration obtained in earlier studies with 3.5- or 7.0-kHz high-resolution acoustical equipment (Lineback et al., 1971).



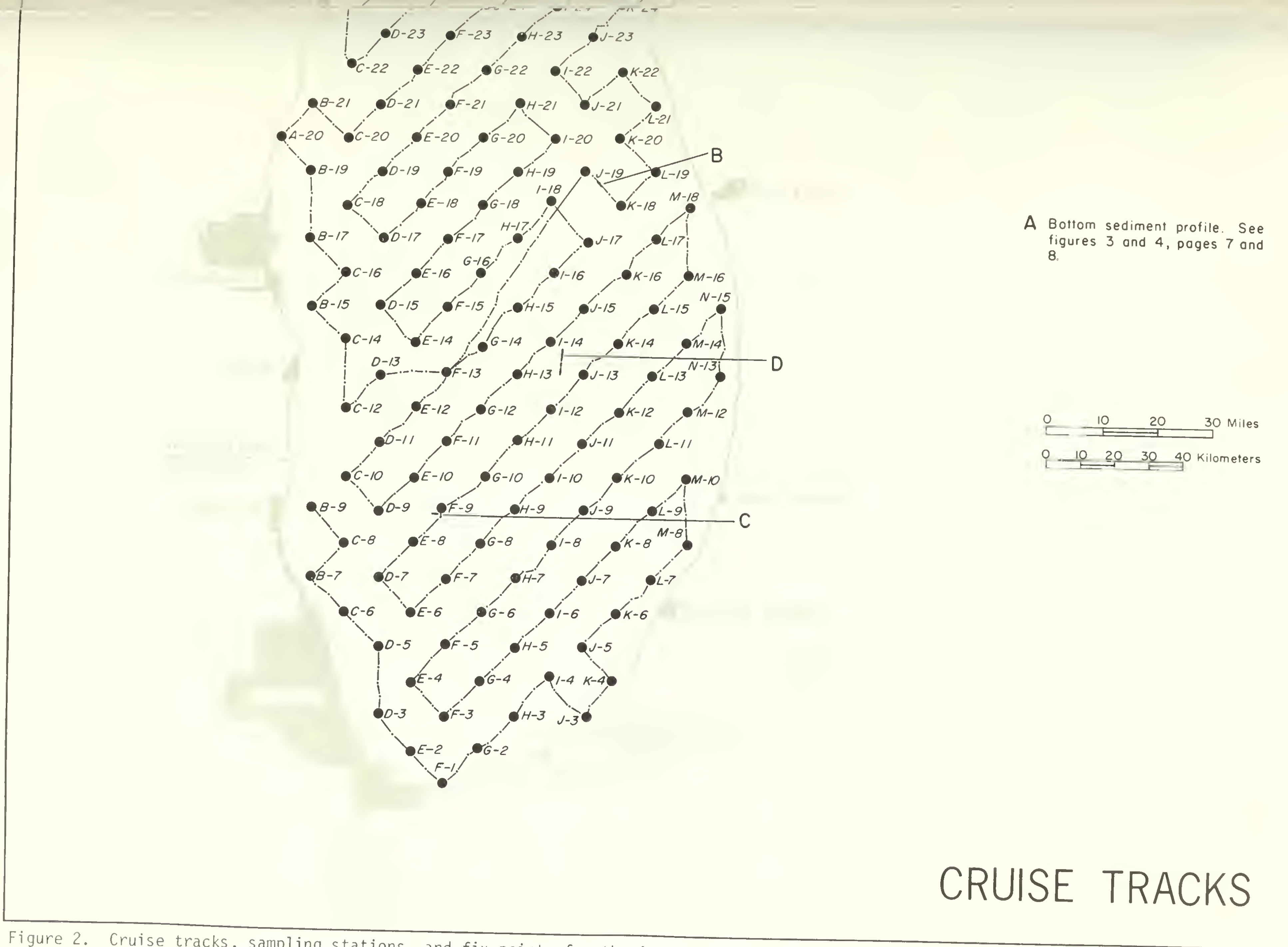


Figure 2. Cruise tracks, sampling stations, and fix points for the August 1975 cruise of the C.S.S. *Limnos*. Acoustical echograms were taken continuously along most of the cruise track.

Nevertheless, the 3000 kilometers of profiles obtained in 1970, 1971, and 1972 may be correlated with the 5140 kilometers of profiles obtained in 1975; both methods produced data from which stratigraphic interpretations may be derived.

The arcuate pattern of the Kelvin Hughes echogram (fig. 3) resulted from mounting an electrical recording pen on a spinning disk and recording on a continuous strip chart. The more easily interpreted rectilinear pattern of the 3.5- or 7.0-kHz records (fig. 4) is the result of mounting the electrical pen on a lead screw and recording on paper on a spinning drum (Lineback et al., 1971, p. 8-9).

Figures 3 and 4 show the acoustical transparency of the lacustrine sediment sequence of the Lake Michigan Formation. The Equality Formation, where present, appears as a series of closely spaced acoustical reflectors. Because the glacial till underlying the lacustrine sequence scatters and absorbs most of the acoustical energy, reflectors within the till are rare.

The Lake Michigan Formation can be divided into two acoustical units (fig. 3). The upper unit consists of closely spaced reflectors and is generally gray clay comprising the Waukegan, Lake Forest, and Winnetka Members. The lower unit is acoustically transparent, has few internal reflectors, and includes the red clay belonging to the Sheboygan and South Haven Members.

Echograms of the Lake Michigan Formation, particularly of the red clays, differ somewhat for the south and north ends of the lake. In the south, the division of red and gray clay is generally sharp (fig. 3). In the central part of the lake, red clays sometimes have strong reflectors within the sequence. In the north, where many prominent reflectors are found in the red clays (fig. 3), it may be difficult to distinguish the red clay from the Equality Formation. In the northern basin, the gray clay may be acoustically more transparent than the red clay. The lateral changes within the red clay are related to distances of sediment transport.

The red clays were derived from outwash of the glacier that deposited the Two Rivers Till during the Valderan Substage* (Lineback, Dell, and Gross, in press). As the "Two Rivers" glacier melted out of the northern part of the lake, a coarse material that now acts as an acoustical reflector in the clay sequence was deposited within the red clay. Only fine material was deposited in southern Lake Michigan, more than 120 kilometers from the melting glacier; therefore, the red clays in that part of the lake have few acoustical reflectors.

*In 1976, Evenson and others proposed that the Valderan Substage be renamed the *Greatlakean Substage* in Michigan and Wisconsin. Because *Valderan Substage* is more widely known, that name is used here.

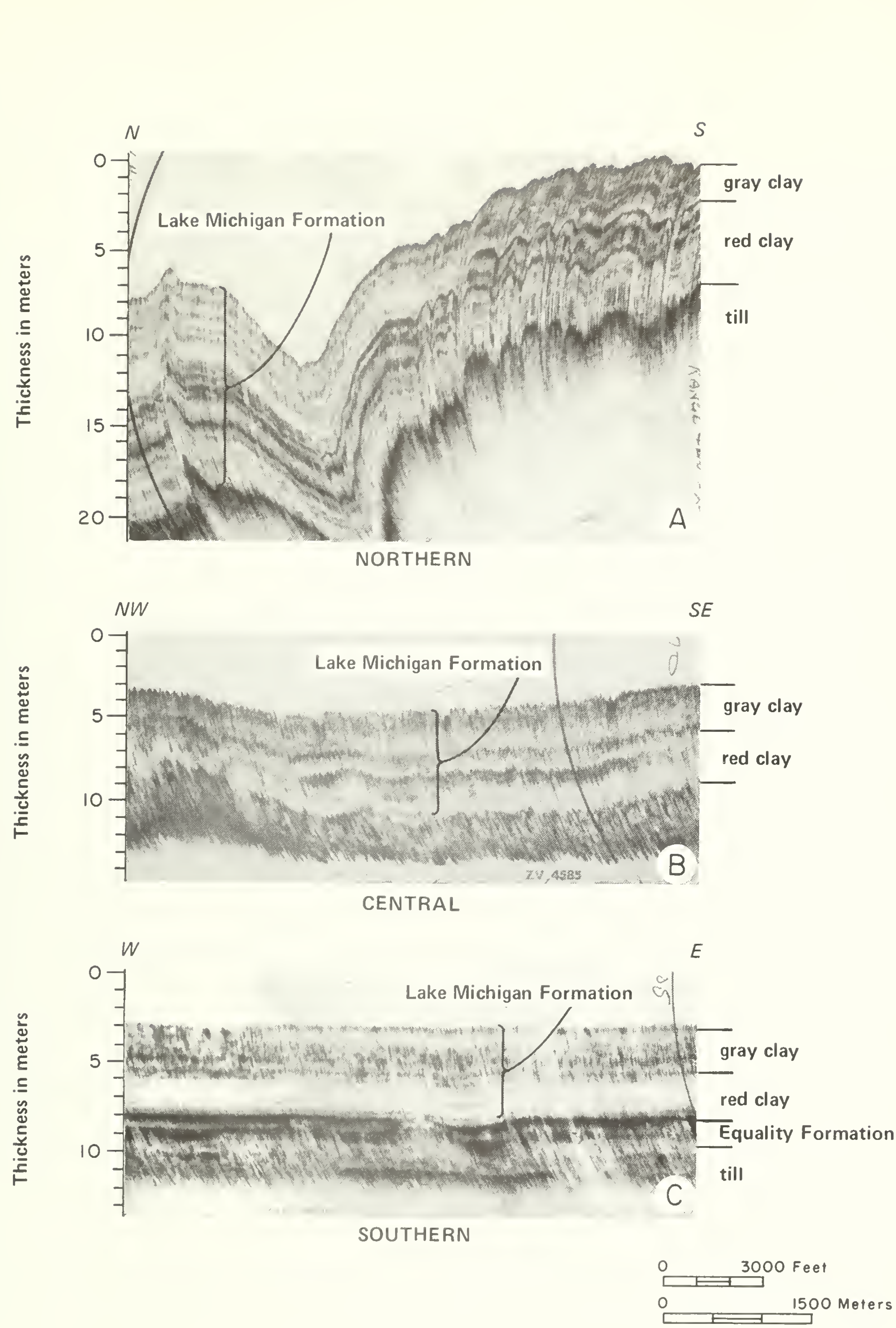


Figure 3. Echograms from the southern, central, and northern parts of Lake Michigan showing the acoustical characteristics of the red and gray clays of the Lake Michigan Formation. Locations shown in figure 2.

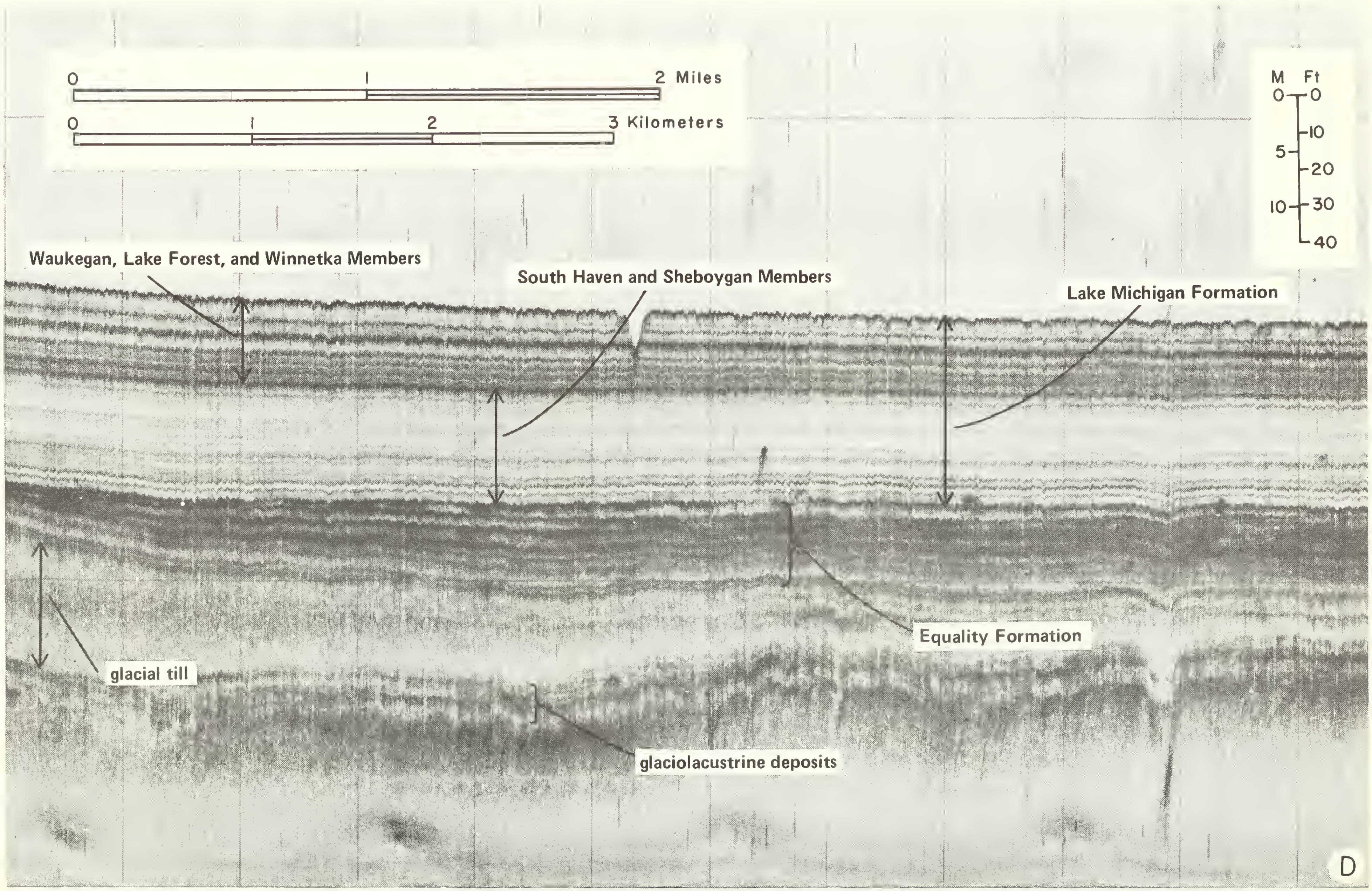


Figure 4. Example of a high-resolution profile of Lake Michigan bottom sediments taken during a cruise in October 1972. Location shown in figure 2.

topography of the lake floor

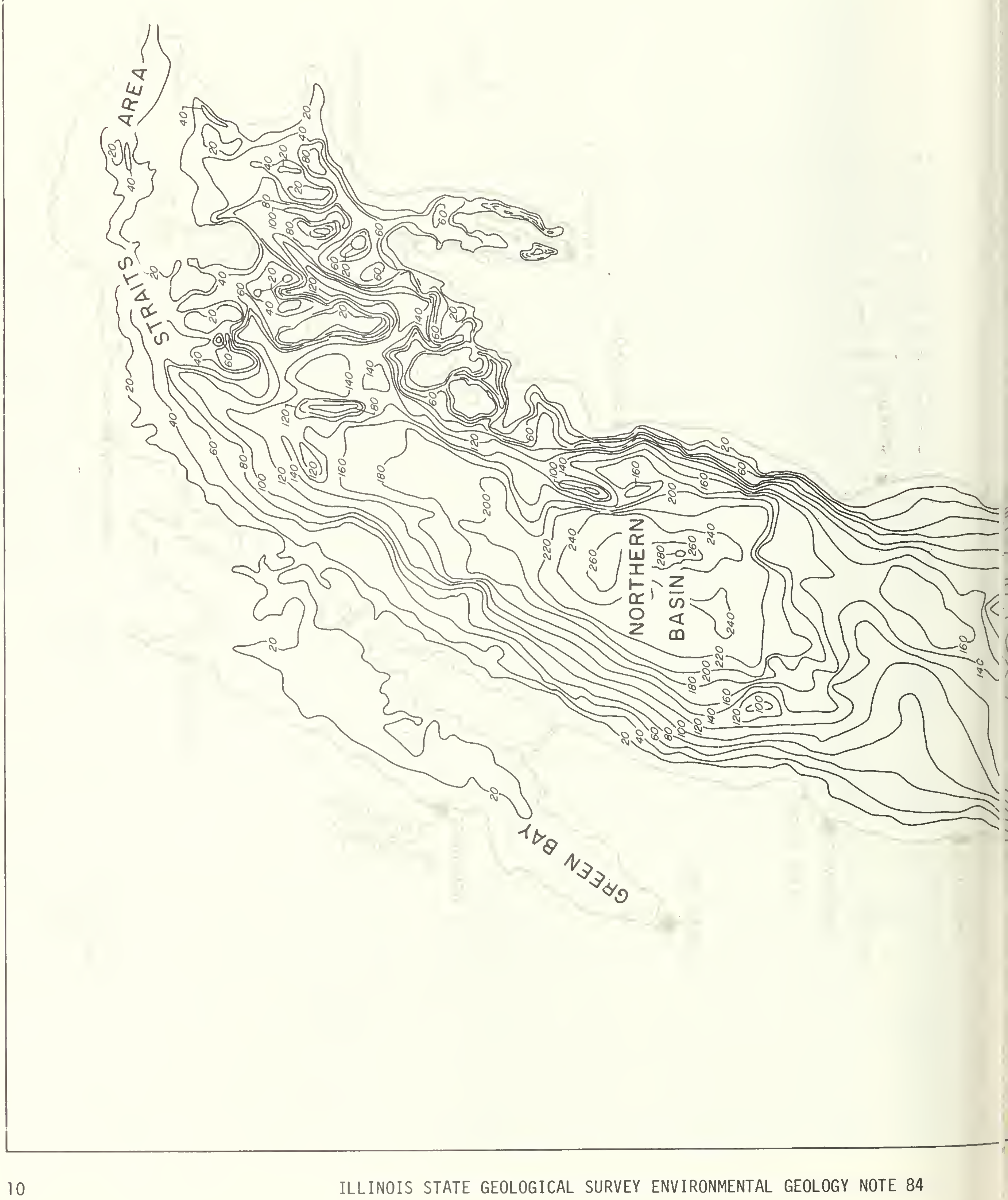
The complexity of the Lake Michigan floor, as shown by depth of water below mean lake level (fig. 5), resulted from three influences: (1) lithology and structure of the Paleozoic bedrock, (2) large-scale erosion by continental glaciers, and (3) deposition of glacial and postglacial sediment in the basin. The lake basin parallels the strike of the Paleozoic bedrock. A bedrock map of the United States demonstrates the remarkable parallel between the elongate shape of the lake basin and the strike of bedrock outcrops curving around the west side of the Michigan Basin (Hough, 1958). The lake basin was carved by southward-flowing continental glaciers. Erosion probably began early in the Pleistocene and certainly continued through the advance of the glaciers during the Woodfordian Substage of the Wisconsinan. During the waning of the Woodfordian and during the Valderan Substage, a series of tills and glaciolacustrine and lacustrine sediments was deposited in the basin and now almost completely covers the Paleozoic bedrock in the southern two-thirds of the lake. Areas of exposed bedrock, such as the Mid-lake High east of Milwaukee, are scattered over the lake floor and are especially pronounced in the northeastern corner. Because no tills older than the Woodfordian have been found under the lake, each major glacial advance must have eroded and removed deposits from earlier glaciations.

The bottom topography of Lake Michigan was described on a Lake Michigan Chart No. 7 (1:500,000) from U.S. Army Corps of Engineers soundings. U.S. Army Corps of Engineers Charts No. 73 to 77 and 701 to 706 and Emery's Bathymetric Chart of Lake Michigan (1951) are more detailed.

Emery (1951) subdivided the floor of Lake Michigan into five physiographic provinces, which we now call the southern basin, the Mid-lake High, the northern basin, Green Bay, and the straits area.

The southern basin

The southern basin is smooth-sided and has a maximum depth of 163 meters (fig. 5). On the basin's eastern side, the lake floor descends rapidly to deeper water, whereas the western and southern sides of the basin slope more gently. A steep rise begins approximately 15 kilometers from the eastern shore at Benton Harbor, Michigan, and extends to the Mid-lake High. On the basis of the Paleozoic bedrock units known to lie under the lake, Lineback, Gross, and Meyer (1972) inferred that the eastern escarpment was underlain by siltstone of the Coldwater Formation (Valmeyeran) and attributed formation of the escarpment to the motion of glacial ice in the center of the lake basin. Apparently the erosive action of ice in the southern basin was


STRAITS AREA
NORTHERN BASIN
GREEN BAY

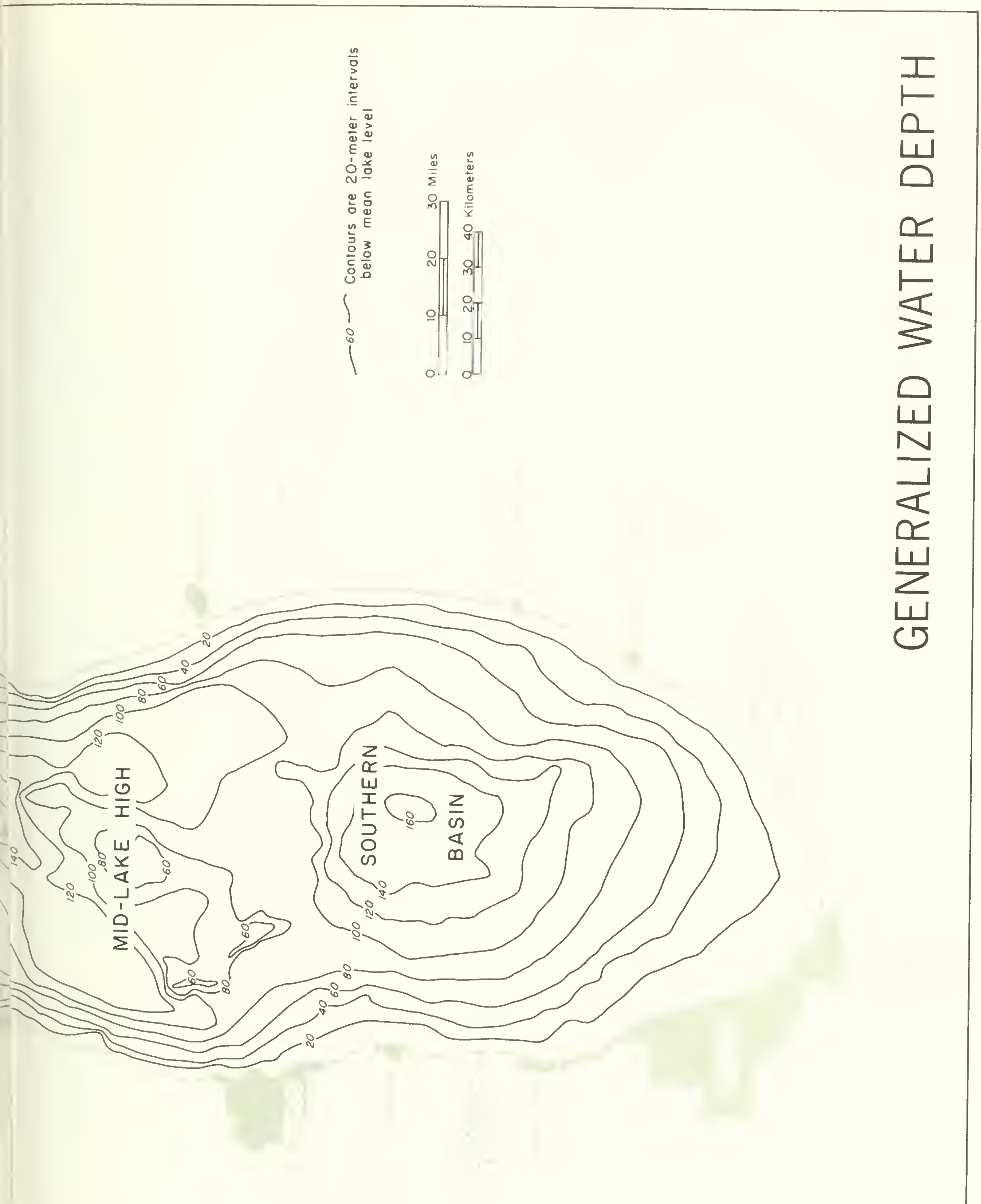

GENERALIZED WATER DEPTH
60 Contours are 20-meter intervals below mean lake level
0 10 20 30 Miles
0 10 20 30 40 Kilometers
MID-LAKE HIGH
SOUTHERN BASIN
20
40
60
80
100
120
140
160

Figure 5

concentrated along soft shales of the Devonian and lower Mississippian in the center of the basin; the Coldwater Formation on the eastern side was not as extensively eroded.

The Mid-lake High

The Mid-lake High is an area of bedrock-controlled topographic highs in the center of the lake east of Milwaukee. In some places, the bedrock is as shallow as 22 meters below the present level of the lake. The bedrock knobs are covered by till and other glacial sediments. Deepwater basins partially flank the Mid-lake High on both the east and the west (fig. 5). The area appears to be composed of resistant Silurian and Devonian carbonate bedrock that was not extensively eroded by Pleistocene glaciers.

The northern basin

According to U.S. Army Corps of Engineers measurements, the deepest point in Lake Michigan is in the northern basin and is 923 feet (281 m). In 1972 and 1975, in the area of the deepest point, the maximum depth encountered by Survey personnel using seismic reflection equipment and the ship's depth sounder was less than 900 feet (274 m).

The topography of the northern basin is more irregular than that of the southern basin. Small ridges and valleys are present throughout the floor of the deepwater basin. A generally smooth and uniform slope extends down the western side of the basin to a depth of approximately 180 meters. Hough (1958) suggested that the western slope of the lake correlated with the dip slope of the resistant Niagaran dolomite (Silurian). On its eastern side, the northern basin is bordered by an offshore bedrock escarpment that extends north to south along a chain of islands in northeastern Lake Michigan.

Green Bay

Green Bay is a relatively shallow body of water; its mean depth is approximately 25 meters. The bay is separated from Lake Michigan by the Niagaran Escarpment (Silurian dolomite), which forms a peninsula and chain of islands on the eastern side of the bay. Green Bay was formed by glacial scour of the underlying weakly resistant rocks.

The straits area

In the straits area (fig. 5), the lake floor has steep ridges, narrow depressions, and bedrock pinnacles. In the extreme northern end of the lake, most of the lake bottom is exposed bedrock. A narrow canyon that once served as a drainageway extends across the lake bottom from the Straits of Mackinac to a shallow divide 72 kilometers west of the straits (Stanley, 1938). The irregular topography of the straits area is mainly due to differential erosion of the lake floor by glacial ice movement (Shepard, 1937, and Emery, 1951). An alternating sequence of resistant and nonresistant rock units within the Traverse Group (Devonian) can be assumed to lie under the straits area from the northwestern region of southern Michigan. Subsidence due to solution cavities within the underlying salt and gypsum beds of the Silurian Salina Group may also have affected the topography of the straits area (Hough, 1958).

stratigraphy of Lake Michigan sediments

Glacial tills of Lake Michigan are overlain by coarse-to-fine-grained glaciolacustrine deposits (fig. 1). These are overlain in turn by glaciolacustrine clay and postglacial silty clay. Because the stratigraphy and composition of these units have already been treated in detail (Lineback, et al., 1971; Gross et al., 1972; Lineback, Gross, and Meyer, 1972 and 1974; and Lineback, Dell, and Gross, in press), they are only briefly outlined here.

Wedron Formation

Three glacial tills of Woodfordian and one of Valderan age (all late Wisconsinan) under Lake Michigan have been identified (Lineback, Gross and Meyer, 1974, and Evenson et al., 1976). No additional tills were differentiated by the 1975 profiling. Each till represents a minor readvance of the waning Wisconsinan ice sheet; each succeeding advance failed to reach as far south as the previous one. Terminal moraines under the lake mark the limits of these ice sheets. The top of the till is often the deepest reflecting horizon on the echograms. Reflecting horizons within or below the till were recorded in only a few places.

Wadsworth Till Member. The oldest known till under Lake Michigan extends on land to include the Lake Border and part of the Valparaiso Morainic Systems around the southern end of the lake. The Wadsworth Till Member is gray (10YR 5/1), but has pinkish-gray (5YR 6/2)streaks in some places. The Wadsworth is a silty clay till dominated by illite in the clay minerals (table 1) and by dolomite in the carbonates.

Shorewood Till Member. The Shorewood is a silty clay till that is intermediate in color and composition between the Wadsworth and Manitowoc Tills. The Shorewood contains more expandable clay minerals, chlorite, and vermiculite and less illite than the Wadsworth (table 1). It is pinkish-, brownish-, or reddish-gray rather than gray, like the Wadsworth, or brown to reddish brown, like the Manitowoc. In the Shorewood, dolomite is more abundant than calcite, but, like the Wadsworth, the Shorewood is lower in total carbonate than the overlying tills. The Shorewood is similar to the overlying red tills and unlike the Wadsworth in that it contains vermiculite derived from iron-rich chlorite in the less-than-2-μm fraction.

Manitowoc Till Member. The Manitowoc is a brown to reddish-brown clayey till that is believed to be the youngest till of Woodfordian age in the Lake Michigan Basin. The Manitowoc contains more expandable clay minerals and less

illite than the Shorewood. The Manitowoc also contains more total carbonate, in which dolomite predominates.

Unnamed formation

Two Rivers Till Member. The Two Rivers Till was named by Evenson (1973) and overlies the Two Creeks forest bed in Wisconsin. The Two Rivers was considered a member of an unnamed formation of Valderan age by Lineback, Gross, and Meyer (1974). The 1974 report by Lineback, Gross, and Meyer and table 1 of this report show the less-than-2-μm fractions of the Two Rivers and Manitowoc Tills to contain nearly equal amounts of expandables, illite, and chlorite. Recent analyses of additional till samples indicate that the Two Rivers Till may have less illite than the Manitowoc (H. D. Glass, personal communication).

Equality Formation

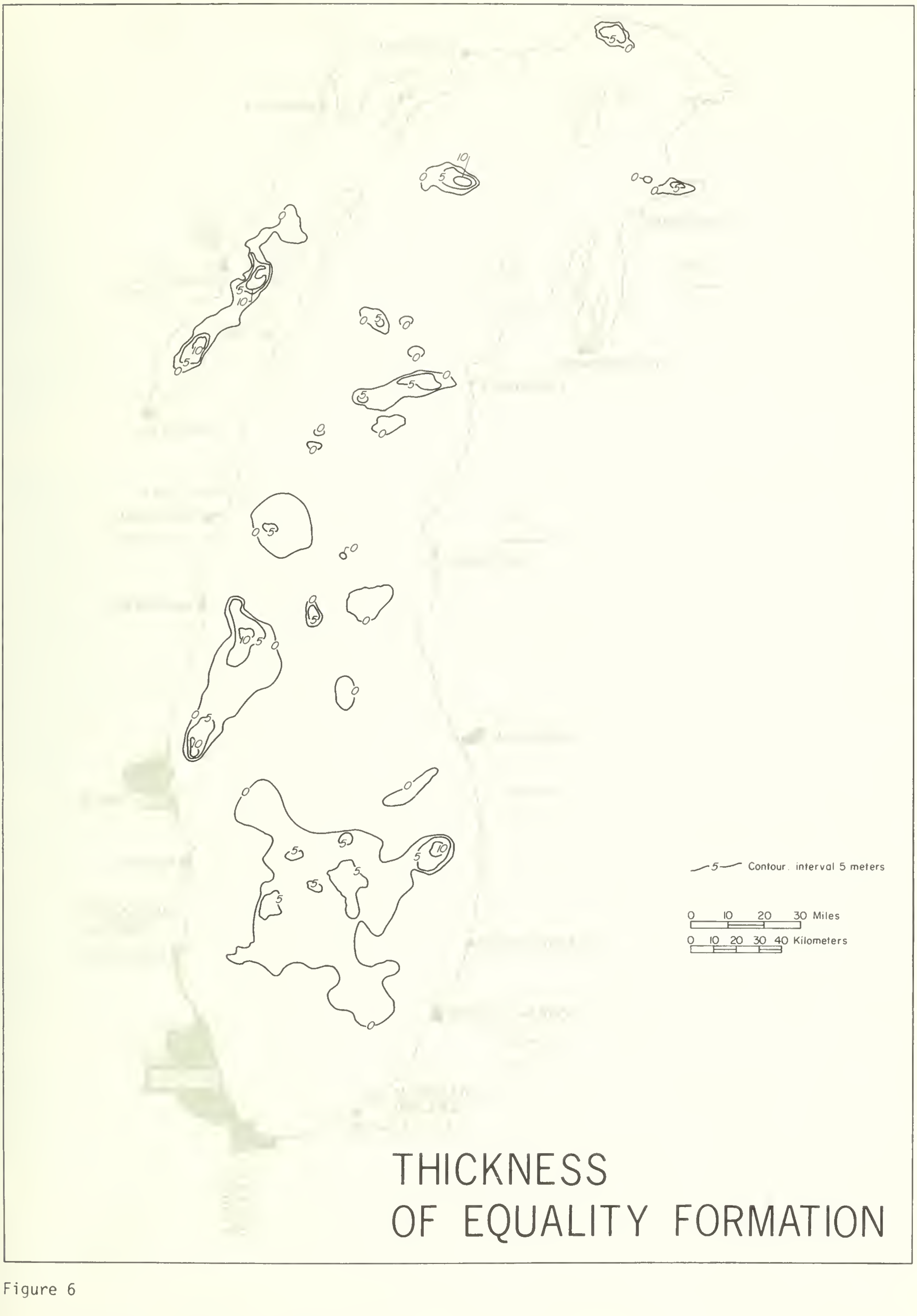
Carmi Member. Coarse-grained deposits that have many variable intercalations lie between the till and the very clayey Lake Michigan Formation. The presence of gravels and the contorted bedding features found in cores are indications of sediment deposition close to a melting glacier. The Equality is recognized on echograms by closely spaced reflectors; it is considerably less transparent acoustically than the Lake Michigan Formation. The Equality is generally thin but is over 10 meters thick in some places (fig. 6). It is thickest in the deepest parts of the lake and most widespread in the southern basin. Where it is less than 1 meter thick, the Equality is difficult to recognize on the echograms. The Equality was formed by glaciolacustrine deposition during the melting and readvances of glaciers that deposited the late Wisconsinan tills. Deposition lasted longer in the southern basin, which was deglaciated about 13,000 radiocarbon years B.P., than in the northern part of the lake, which was deglaciated about 11,500 radiocarbon years B.P.

TABLE 1. Composition of Lake Michigan sediments

	Average grain-size composition (%)					Average composition of <2-μm fractions					
Stratigraphic unit	Gravel	Sand	Silt	Clay (<2 μm)	Number of samples	Expandables (%)	Illite (%)	Chlorite (%)	Calcite (counts/sec)	Dolomite (counts/sec)	Number of samples
Lake Michigan Formation											
Waukegan Member	1	8	41	51	51	22	49	29	5	4	42
Lake Forest Member	0	4	39	57	75	23	46	31	17	11	69
Winnetka Member	0	2	39	59	114	22	46	32	15	13	110
Sheboygan Member											
Upper part	0	1	26	73	35	27	35	38	7	9	33
Wilmette Bed	0	1	17	82	17	25	36	39	1	5	16
Lower part	0	1	14	85	41	28	33	39	0	3	38
South Haven Member	0	1	19	80	46	26	36	38	0	4	47
Equality Formation											
Carmi Member	4	8	54	34	49	22	46	32	8	19	46
Unnamed formation											
Two Rivers Till Member			n.d.[a]			22	55	23	72	51	6
Wedron Formation											
Manitowoc Till Member			n.d.			21	56	23	65	113	20
Shorewood Till Member			n.d.			17	63	20	50	66	4
Wadsworth Till Member	4	11	46	39	5	8	72	20	42	52	15

(Table modified from Gross, et al., 1972, and Lineback, Gross, and Meyer, 1974).

[a]No data



THICKNESS
OF EQUALITY FORMATION
Contour interval 5 meters
0 10 20 30 Miles
0 10 20 30 40 Kilometers

Figure 6

The composition of the Equality varies slightly, depending on the till unit with which it is associated; therefore, Equality deposits may be similar in mineralogy to any of the major till units. Equality deposits range in age from late Woodfordian into the Valderan. The average composition of nearly 50 Equality samples indicates a carbonate-bearing silty clay containing more illite and less expandables and chlorite than the overlying red clay of the Lake Michigan Formation (table 1).

During several intervals of late Woodfordian deglaciation, the glacial Grand River of Michigan carried drainage from the Lake Huron Basin into the Lake Michigan Basin (Eschman and Farrand, 1970). A fairly extensive delta deposit accumulated between Holland and Grand Haven, Michigan. Equivalent deepwater deposits were identified under the lake near Grand Haven by Lineback, Gross, and Meyer (1972) and are assigned to the Carmi Member. No core has penetrated these deposits, but echograms from the area show many strong internal reflectors in over 10 meters of sediment (fig. 6). Other Equality accumulations that are thick locally on the lake floor may be outwash deposits carried by streams from melting glaciers.

Lake Michigan Formation

A sequence of red, brown, and gray clays, ranging in thickness from 0 to 22 meters, overlies the tills and the Equality Formation (figs. 1 and 7). These clays are divided into five members and one bed under the lake. An additional member, the Ravinia Sand, includes the modern beach sands. Deposition of the Lake Michigan Formation apparently began when the ice sheet that deposited the Two Rivers Till began to melt. The basal red clays are glaciolacustrine rock-flour deposits (Gross et al., 1972). The younger brown and gray clays are postglacial deposits derived from shoreline erosion and from sediment carried into the lake by streams and rivers.

The Lake Michigan Formation appears to be more transparent acoustically than the underlying Equality Formation or the glacial till (fig. 3). The thickness of the Lake Michigan Formation, as determined by acoustical characteristics, is shown in figure 7. There may be places on the map where the acoustically transparent Equality Formation has been included in the Lake Michigan Formation or other places where not all of the Lake Michigan Formation was recognized because of variable acoustical conditions in the sediment. The thickness of the Lake Michigan Formation in deepwater areas is remarkably uniform from south to north in the lake. The formation is more than 15 meters thick in most of the deepwater basins. Lesser thicknesses are noted on topographic highs. Some sediment in shallow water at the north end of the lake is included in the Lake Michigan Formation because it appears to be acoustically similar.

The Lake Michigan Formation has been subdivided into two acoustically recognizable units (fig. 3). The lower unit is transparent and has few internal reflectors. In cores, it generally consists of red clay and corresponds to the combined South Haven and Sheboygan Members (fig. 8). The overlying unit contains a greater number of reflecting units and consists of gray clay that corresponds to the combined Winnetka, Lake Forest, and Waukegan Members (fig. 9).

South Haven and Sheboygan Members. Red clays (the combined South Haven and Sheboygan Members) are confined to the deepwater basins of the lake. They are more than 10 meters thick in these deepwater areas and in some places are more

than 15 meters thick (fig. 8). There seems to be no significant north-to-south thinning in the red clays. Over most of the lake, red clays are found only at depths greater than 82 meters below present lake level. Because the red clays show no particular area of thickening and because they are so fine grained, they were probably deposited by the settling of suspended rock flour distributed almost equally throughout a proglacial lake during the melting of Valderan glaciers. See Lineback, Dell, and Gross, in press, for a detailed account of lake history.

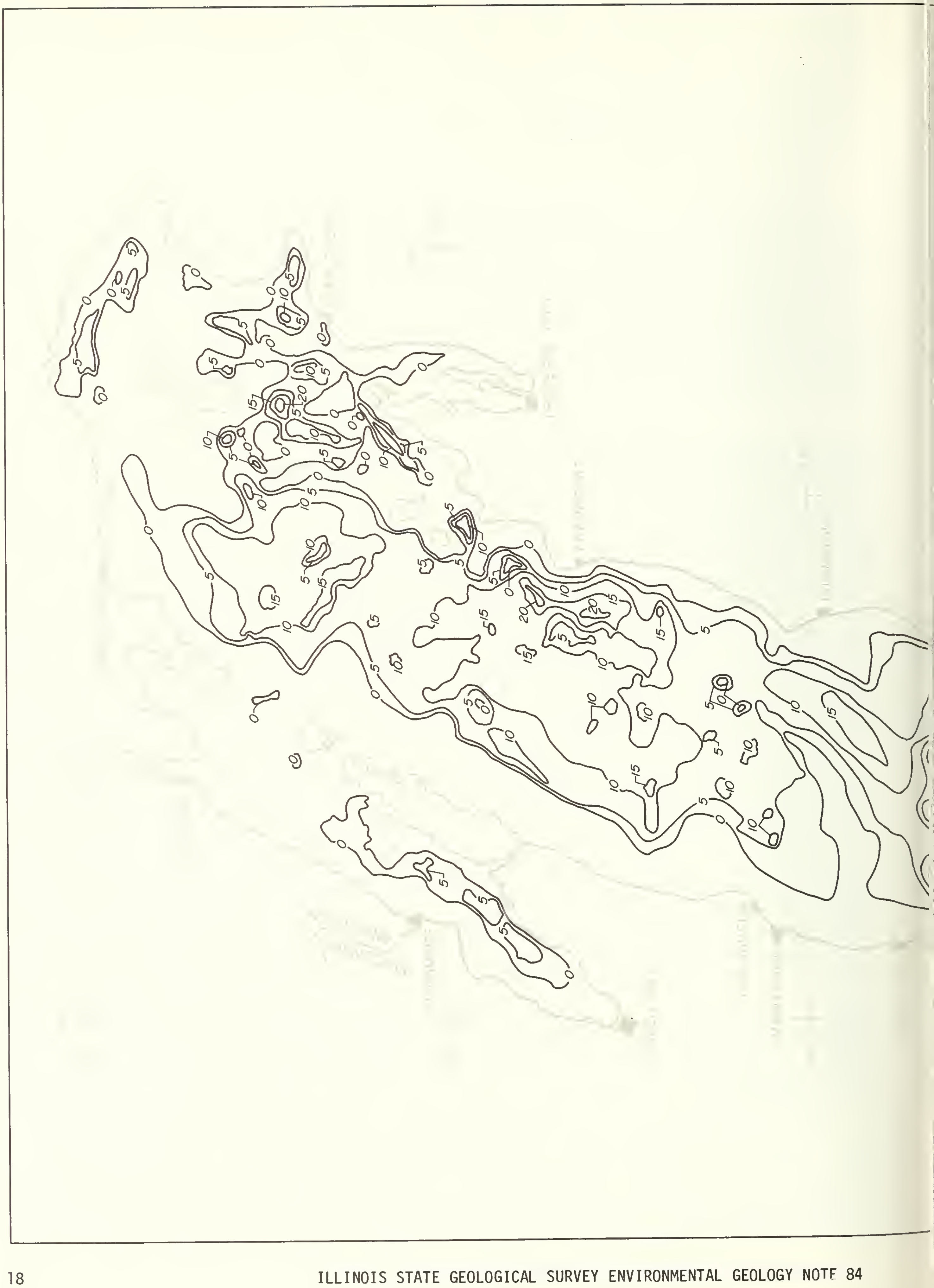
South Haven Member. In the basal member of the Lake Michigan Formation (fig. 4), an average of 80 percent and as much as 98 percent of the reddish-brown (5YR 5/3) sediment is less than 2 μm (table 1). This clay is exceedingly fine grained; 20 to 40 percent of the clay in some samples is less than 0.125μm. The clay minerals show less illite and more expandables and chlorite than the Equality Formation (table 1). The clays also contain an abundance of clay-sized particles of quartz, feldspar, and other minerals that are typical of glacial outwash except for an absence of calcite and an almost complete absence of dolomite.

The low carbonate content is puzzling, since the Two Rivers Till, presumably derived from the same source, is high in carbonate. This difference in carbonate composition may be partially explained by the relatively long time rock flour remained suspended in cold lake water. The glacier that contributed the South Haven Member and at least part of the overlying Sheboygan Member never reached much farther south than Manitowoc, Wisconsin (Lineback, Gross, and Meyer, 1974). As this glacier retreated (beginning about 11,500 radiocarbon years B.P.), coarse outwash was deposited near the ice front. Rock flour, consisting largely of less-than-2μm material, remained suspended and spread throughout the lake. Thus, several meters of South Haven are found near Waukegan, Illinois, more than 120 kilometers south of the nearest possible source and more than 200 kilometers from the likely ice front. The long suspension in a cold, ice-marginal lake probably resulted in solution of the carbonates (Gross et al., 1972).

The South Haven has faint color bands and, in some places, thin beds of brown silt. No varves are evident south of Milwaukee. Possible varves have been identified only in a few cores taken from an area north of Milwaukee.

Sheboygan Member. The lower part of the Sheboygan Member is even more clayey than the South Haven (table 1), is more intensely reddish brown (5YR 5/4, 4/4), and has thicker color banding. The Sheboygan Member contains the Wilmette Bed, a thin (6 to 22 centimeters) marker bed of dark gray (5YR 4/1) clay that is otherwise similar in composition to the underlying Sheboygan (table 1). The low level of carbonates indicates that the material in this bed was transported in suspension for a long time and may represent outwash from possible gray till sources northeast of Lake Superior (Lineback, Dell, and Gross, in press). The Wilmette contains streaks of black clay and faint mottling of lighter and darker gray clay. Its top is often sharp and its base gradational.

The Sheboygan above the Wilmette Bed is reddish-gray clay (5YR 5/2, 5/3, 5/4), but differs importantly from the Sheboygan below the Wilmette in that it consistently contains carbonates. It is also slightly coarser grained (table 1), which, with the increase in carbonate, indicates that the upper part of the Sheboygan was affected by a decrease of distantly transported material



THICKNESS OF THE LAKE MICHIGAN FORMATION

Figure 7

and a relative increase in locally derived sediment. Warming of the lake after withdrawal of the ice may also have caused the increase in carbonates.

Winnetka, Lake Forest, and Waukegan Members. The gray sequence (Winnetka, Lake Forest, and Waukegan Members combined) overlaps the red clays and is found over all but the shallow and nearshore areas of the lake. Where the sediment surface is sandy or where the gray clays are thin (less than 1 meter), it is difficult to delineate the sequence on the echograms. Therefore, in areas outside the zero-thickness line (fig. 9), a few centimeters of gray silt or clay are often above the till. The gray clay is slightly over 5 meters thick in the deepwater areas and up to 18 meters thick in a band along the eastern shore from Ludington, Michigan, to Michigan City, Indiana, and west of Traverse Bay.

Winnetka Member. The Winnetka Member is a brown (7.5YR 5/2) silty clay markedly coarser grained than the underlying Sheboygan (table 1). There are also important mineralogical differences between the Sheboygan and Winnetka, namely, illite and carbonates increase and chlorite decreases. Most of the sediment in the Winnetka and younger units was derived from shoreline erosion and by stream erosion within the Lake Michigan drainage basin (Gross et al., 1972). Erosional unconformities at the base of the Winnetka are frequently marked by a thin bed of sand (Hough, 1958). Truncation of the red clays below the Winnetka is prominent in areas where the lake is shallower than 82 meters below present lake level.

Lake Forest Member. The Lake Forest Member consists of gray (10YR 5/1) silty clay with abundant black beds 1 to 10 millimeters thick separated by 1 to several centimeters of gray clay that contains black mottling. Its mineralogy is similar to that of the Winnetka (table 1).

Waukegan Member. The Waukegan Member is present over most of the floor of Lake Michigan where sediments are currently accumulating. Along the east side of the southern lake basin, the Waukegan Member is forming a deltalike wedge of sediment up to 18 meters thick (Lineback and Gross, 1972). The Waukegan consists of dark gray (5YR 4/1) silty clay or clayey silt and contains black beds and mottling. The Waukegan contains less carbonate and chlorite and more illite than the Winnetka (table 1). The sediment is a mixture of material carried in by rivers from southern Michigan and material redistributed by currents.


Contour interval 5 meters
0 10 20 30 Miles
0 10 20 30 40 Kilometers
THICKNESS OF RED CLAY

Figure 8

5 Contour: interval 5 meters
0 10 20 30 Miles
0 10 20 30 40 Kilometers
THICKNESS OF GRAY CLAY

Figure 9

summary of bottom sediment relationships

The oldest known glacial deposits under Lake Michigan are of late Woodfordian age. Glacial deposits are found throughout the lake, but vary regionally in their characteristics and extent.

Till and other glacial sediments crop out on the lake floor in places, especially in the southern part of the lake northeast of Chicago. Till commonly extends from the lake shore, where it is often covered with thin remnants of lake sediments, to the deepwater areas of the southern basin, where it underlies the Lake Michigan Formation. In the northern basin, till is generally overlain by lake sediments and appears as a surficial deposit only in nearshore locations on the western side of the lake. The straits area is underlain by patchy glacial deposits that mainly fill in depressions between bedrock hills.

The gray Wadsworth Till in the southern part of Lake Michigan is significantly different mineralogically from the red Manitowoc Till to the north (Lineback, Gross, and Meyer, 1974). The difference probably resulted from a shift in source area which occurred during deposition of the transitional Shorewood Till Member. The mineralogy of the Wadsworth Till suggests that it derived from Paleozoic bedrock under the lake. The Manitowoc Till and younger tills appear to have derived from sources north and west of the lake. Available data is insufficient to allow a definite explanation of this compositional shift in the till.

The Equality Formation was deposited in proglacial lakes during melting of the receding Wisconsinan glaciers. The composition of the Equality therefore closely matches the composition of the till from which that part of the Equality was derived (Gross and others, 1972).

The basal member of the Lake Michigan Formation is compositionally distinct from the underlying Equality Formation. The extremely fine-grained red clay of the South Haven Member was derived from glacial outwash of the Valderan glacier that advanced only as far as Manitowoc, Wisconsin. The red clay was separated from coarser materials and suspended throughout the lake while the Valderan ice melted from the lake. Discharge of the red clay continued even after the Valderan ice had retreated to the northern peninsula of Michigan. The ice front stabilized there for a thousand years during the "Algonquin Stade" (Saarnisto, 1974; Borns, 1977). Fine-grained glaciolacustrine sediments were carried into Lake Michigan across the northern peninsula of Michigan (Lineback, Dell, and Gross, in press). The red clay, apparently suspended in cold waters for a long period, is largely carbonate free.

An influx of gray clay in Lake Superior during retreat of the ice across that lake may also have resulted in deposition of gray clay in Lake Michigan (Lineback, Dell, and Gross, in press). Gray clay derived from Lake Superior (the Wilmette Bed) is very thin in Lake Michigan and was deposited only until connections between Lakes Superior and Michigan through the Au Train Channel and other possible channels were severed by isostatic rebound of northern Michigan or lowering of the Lake Superior water level. Following cessation of glacial sediment input from Lake Superior, Lake Michigan bottom sediments derived mainly from the surrounding drainage basin.

A low-water lake stage (Chippewa stage; Hough, 1955) followed the end of glaciolacustrine deposition in Lake Michigan. Lake level dropped to an elevation approximately 62 meters below present lake level. The drop in lake level is recorded by the truncation of the Wilmette Bed, lower part of the Sheboygan Member, and South Haven Member at a level about 82 meters below present lake level. The 20-meter interval separating the estimated low level of Lake Chippewa and the level of truncated deposits represents an estimated wave-base above which lake sediments are assumed to have been eroded by wave and current action. The lake clays eroded from exposed parts of the lake and the part of the lake floor in the zone of effective wave and current action were deposited over the Wilmette Bed in the deeper waters of Lake Chippewa. These reworked lake clays, which form the upper part of the Sheboygan Member, display some compositional characteristics acquired from locally derived sediments, including a higher silt and carbonate content.

Lowering during the Chippewa stage was examined in an unpublished Ph.D. thesis by Buckley (1974). Using environmental interpretations of ostracod distribution in the lake sediments of southern Lake Michigan, Buckley found that the lake level during the Chippewa stage may have lowered no more than 61 meters (200 ft). This estimate is in contrast to the widely quoted level of 107 meters (350 ft) used by Hough (1955), but is in accord with the 62-meter level reported above.

Lake Chippewa, although smaller than present Lake Michigan, was a continuous body of water from the southern basin to the straits area. Red clay of the lower two members of the Lake Michigan Formation was identified on echograms in the northern end of the lake at depths shallower than 82 meters. These clays were not eroded during the Chippewa stage because the northern end of the lake was isostatically depressed throughout the Chippewa stage. Subsequent isostatic rebound raised the red clays to higher elevations. Data points for the pinchout of red clay were not numerous enough to allow the plotting of a rebound curve, but the hingeline appears to be in the vicinity of Frankfort, Michigan.

Following erosion of the exposed red lake clays during the Chippewa stage, sediments derived from shorelines and rivers within the Lake Michigan drainage basin had an increasingly significant input into Lake Michigan bottom sediments. This is evident in the stratigraphic break between the red upper part of the Sheboygan Member and the brown Winnetka Member. Paleomagnetic dating of the Winnetka Member places the beginning of its deposition at the Wisconsinan-Holocene boundary of about 7000 radiocarbon years B.P. (Creer, Gross, and Lineback, 1976).

Sedimentation in Lake Michigan continued to reflect the shift toward sources within the drainage basin in the deposition of the Lake Forest and Waukegan Members. Both members are coarser grained and have higher illite contents than their underlying units. The Waukegan Member is thickest in deltalike deposits along the eastern side of the lake. These sediment bodies appear to have developed from postglacial sediment from streams in western Michigan.

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1. EGN 30—Preliminary Stratigraphy of Unconsolidated Sediments from the Southwestern Part of Lake Michigan. 1970.
2. EGN 32—Distribution of Major, Minor, and Trace Constituents in Unconsolidated Sediments from Southern Lake Michigan. 1970.
3. EGN 35—Stratigraphy of Unconsolidated Sediments in the Southern Part of Lake Michigan. 1970.
4. EGN 37—Distribution of Arsenic in Unconsolidated Sediments from Southern Lake Michigan. 1970.
5. EGN 39—Phosphorus Content in Unconsolidated Sediments from Southern Lake Michigan. 1970.
6. EGN 41—Trace Element and Organic Carbon Accumulation in the Most Recent Sediments of Southern Lake Michigan. 1971.
7. EGN 44—Distribution of Mercury in Unconsolidated Sediments from Southern Lake Michigan. 1971.
8. EGN 47—High-Resolution Seismic Profiles and Gravity Cores of Sediments in Southern Lake Michigan. 1971.
9. EGN 54—Geologic Cross Sections Derived from Seismic Profiles and Sediment Cores from Southern Lake Michigan. 1972.
10. EGN 58—Depositional Patterns, Facies, and Trace Element Accumulation in the Waukegan Member of the Late Pleistocene Lake Michigan Formation in Southern Lake Michigan. 1972.
11. EGN 69—Glacial Tills under Lake Michigan. 1974.
12. EGN 74—A Side-Scan Sonar Investigation of Small-Scale Features on the Floor of Southern Lake Michigan. 1975.
13. EGN 84—Late Quaternary Sediments of Lake Michigan. 1978.


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